An 8.4-GHz Dual Maser Front End for Parkes Reimplementation

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An 8.4-GHz front-end system consisting of a feedhorn, a waveguide feed assembly, dual masers, and downconverters is being reimplemented at Parkes as part of the Parkes–Canberra Telemetry Array for the Voyager Neptune encounter. The front-end system was originally assembled by the European Space Agency on the Parkes antenna for the Giotto project. It was also used on a time-sharing basis by the DSN as part of the Parkes–Canberra Telemetry Array to enhance the data return from Voyager 2 at Uranus. At the conclusion of these projects in 1986, the front-end system was dismantled, packed, and shipped to Europe. Part of the system was then shipped to JPL on loan for reimplementation at Parkes for the Voyager Neptune encounter. The system is being redesigned and refurbished for operation at Parkes. Tasks include new microwave front-end control cabinets, a closed-cycle refrigeration data acquisition system, a new noise-adding radiometer system, a front-end controller assembly, and refurbishment of the dual 8.4-GHz traveling-wave masers (TWMs) and waveguide feed system.

I. Introduction

The 8.4-GHz front-end system was installed on the Parkes antenna in 1985. It was originally assembled by the European Space Agency (ESA) for the Giotto project. The RF package (Fig. 1), containing a waveguide feed system, dual traveling-wave maser and closed-cycle refrigerator assemblies (TWM/CCRs or TWMs), and the TWM monitor and control instrumentation, was built by Airborne Instrument Laboratories (AIL). JPL provided the waveguide feed system, the TWM design based on the JPL Block IIA TWM [1], the TWM monitor and control instrumentation design, and technical consulting during the manufacturing and testing of the system. As a result of an agreement between NASA/JPL and ESA, the front-end system was also used on a time-sharing basis by the DSN as part of the Parkes-Canberra Telemetry Array to enhance the data return from Voyager 2 at Uranus. At the conclusion of these projects in 1986, the front-end system was dismantled, packed, and shipped to Europe. Part of the system was then shipped to JPL on loan for reimplementation at Parkes for the Voyager Neptune encounter. New developments to make the system operable at Parkes include new microwave front-end control cabinets, a closed-cycle refrigeration (CCR) data acquisition system, a new noise-adding radiometer (NAR) system, a front-end controller (FEC) assembly, and refurbishment of the dual 8.4-GHz traveling-wave masers (TWMs) and waveguide feed system.

During the upcoming Voyager Neptune encounter, ESA will no longer be responsible for the maintenance and operation of the Parkes antenna front-end system. As the decision has been made not to replicate the ESA-designed monitor and control system (designed around an HP computer), a new system will be built around an Intel Multibus computer similar to the PCTA receiver/combining system. Advantages of this approach include automated operation with the PCTA Parkes site, the availability of status information (and to some extent control) remotely at the Canberra site, and the ability to share common spares with PCTA equipment.

In addition to the front-end monitor and control, a noise-adding radiometer (NAR) function will be added to the system. Intended primarily to aid antenna pointing calibration procedures, the NAR will be capable of monitoring system temperature either pre-pass or during Voyager tracking.

II. Parkes Front-End Description for the 1986 Uranus Encounter

The 1986 configuration consisted of the following:

(1) Aerial cabin equipment, which included the feed and all microwave components, TWM low-noise amplifiers, downconverters, an upconverter, test signal switching, noise diode assemblies, and a monitor receiver.

(2) Control room (pedestal) equipment, which included all monitoring and control for the front end.

(3) A compressor room, which contained the helium compressors for the CCRs.

The feedhorn assembly was located at the primary focus of the antenna and was connected to a rotatable polarizer and an orthomode transducer. The system then provided two identical receive channels (for redundancy) using TWMs based on the JPL Block IIA TWMs and operating at 8425 MHz (nominal) with a 100-MHz bandwidth. Downconversion to 325 MHz (nominal) was accomplished with two identical downconverters using fixed-frequency local oscillators at 8100 MHz phase-locked to the station 5-MHz timing. Either of the 325-MHz downconverter outputs could be selected as the input to the short-loop telemetry receiver (not part of the front-end system).

A single monitor receiver with switchable input was provided for monitoring the masers. The 8.4-GHz input signal to the monitor receiver was obtained from couplers located in each of the downconverters. The local oscillator for the monitor receiver was also obtained from the downconverters, and hence the monitor receiver input switching selected both the 8.4-GHz input signal and the local oscillator as a pair. Output was selected at 325 MHz (nominal).

The test signal injection system consisted of a programmable synthesizer operating at 425 MHz (nominal), an upconverter known as the X-band test generator, and a test signal switching and distribution network that allowed selection of different test signals to either maser input or output.

The synthesizer output could be phase-modulated with high-rate data from an external source and was coherent with station timing. Upconversion to 8425 MHz was accomplished with an 8000-MHz fixed-frequency local oscillator that was also coherent with station timing. A wideband output for maser bandpass measurement and a narrowband output for telemetry testing were provided on the upconverter.

The switching network consisted of a monitor/test signal/oscillator assembly and two TWM calibration assemblies based on JPL designs. A test oscillator with no power supply was included but not used.

The noise-adding radiometer consisted of a noise diode assembly and power supply for each maser, a square-law detector operating at 325 MHz from the monitor receiver, and a frequency counter. The noise diode output power levels were continuously adjustable and could be modulated by an external source. The noise output of each assembly was fed to the pre-maser coupler via a hybrid in the corresponding TWM calibration assembly. Noise power was detected with a square-law detector, and the output frequency of the detector was coupled into a frequency counter that interfaced with the HP computer system.

The highly automated front-end monitor and control (M&C) was based on a Hewlett-Packard system with bus extenders from the control room to the aerial cabin. The HP system controlled the waveguide switches and polarizer and interfaced to both downconverters, the monitor receiver, and the upconverter to provide monitoring of 17 different failure alarms. Another interface to the dual TWM control assembly was used to control the test injection switching and to monitor receiver functions. The HP system was also used to monitor the CCRs via an analog interface. This provided the ability to monitor the various CCR internal temperatures as well as gas flow, gas pressures, vac-ion (vacuum pump) current, and drive unit operation. Maser tuning was performed manually using an HP power supply for magnet tuning and JPL-designed solid state pump control units located in the control room.

The dual TWM control assembly was based on a standard DSN version but was modified to accept a TTL computer interface as part of the automation. The control panel was located in the control room, and communication with the aerial cabin assemblies was provided by a two-way serial data link.

Either manual or computer control was possible with this arrangement.

Two multiconductor cables with 50 conductors each and 10 coaxial lines carried all M&C and RF signals through the wrap between the control room and the aerial cabin. The system was designed to run from a primary power source of 240 Vac/50 Hz. Step-down transformers were used to provide 220 and 115 volts where necessary.

The antenna cabin hardware consisted of two full- and one half-size 19-inch relay racks and a welded aluminum frame supporting the dual maser package and associated equipment. The frame and the maser package were transportable as a complete assembly and came with a trolley designed for that purpose. Control room equipment was mounted in two 19-inch instrumentation racks with a desktop HP computer. The helium compressors were freestanding in a room above the antenna azimuth bearing.

III. Reimplementation for Parkes/Neptune

Reimplementation of the front end for the Voyager Neptune encounter required a substantial amount of redesign, procurement, and fabrication due to the absence of some key hardware components. Specifically, all Hewlett-Packard commercial equipment had been removed from the system with the following consequences:

(1) There was no way to control or read the position of the waveguide switches or polarizer (other than by hand).

(2) There was no way to monitor the health and status of the CCRs and compressors other than by personal inspection.

(3) There was no way to monitor the health and status of the downconverters, monitor receiver, or upconverter other than by personal inspection.

(4) There was no automation of system configuration or calibration.

Some consideration was given to purchasing all the missing hardware and software needed for the system to be rebuilt and operated exactly as it was in 1986. However, this was abandoned due to financial and practical considerations.

A number of fundamental constraints apply to the alternative approach taken, namely:

(1) The equipment supplied by ESA is on loan to JPL and may not be modified without prior approval from ESA.

(2) There are a limited number of cables available through the wrap on the Parkes antenna, so any new design should ideally use no more cables than were used in 1986 to do the same job.

(3) The physical space for new equipment is limited and should not exceed that used in 1986, if possible.

(4) Equipment weight in the aerial cabin needs to be minimized to avoid damage to the focus drive gear. (The total weight in 1986 was considered excessive.)

(5) There is no plenum air available in the aerial cabin or in the NASA trailer; however, a limited amount of room air conditioning will be available. The usual constraints of operability, reliability, and maintainability also apply.

IV. Parkes Front-End System for the Neptune Encounter

A. General Description

The RF configuration of the front end (Fig. 2) will be virtually identical to that of the 1986 encounter, with the exception of pre/post-TWM signal coupling ports, provided for the Commonwealth Science Industrial Research Organization (CSIRO) of Australia, which operates and maintains the Parkes antenna. The two new RF front-end control (RFFEC) cabinets (Fig. 3) will be installed in the NASA trailer, requiring two new multiconductors between the antenna pedestal control room and the NASA trailer. The two RFFEC cabinets are the maintenance point for tuning and adjusting the dual TWMs. They contain the monitor receiver display (an HP 8590A spectrum analyzer), the 420-MHz (nominal) test signal source (an HP 8663A synthesizer signal generator), the front-end controller, a CRT terminal, the CCR data acquisition unit, and the TWM monitor and control equipment. The aerial cabin racks A, B, and C (Fig. 4) contain the balance of the front-end RF and TWM/CCR monitor and control equipment. The antenna room racks contain equipment that must be relocated through additional cabling if they are not in close proximity to the TWM/CCRs or the waveguide feed system. The total weight of the front-end equipment (including the RF package) that will be installed in the antenna room is 630 kilograms ±2 percent.

The major changes being made to the front-end system will alter the way in which the system is monitored and controlled. Reimplementation of the Parkes antenna front end will include a system for centralizing and automating the monitoring and control of the microwave electronics (Fig. 5). This monitoring and control will be providėd through the Parkes front-end controller (FEC) assembly, a multibus-based computer mounted in one of the two front-end control cabinets (Fig. 3) located in the Parkes NASA trailer. The FEC will tie together individual pieces of equipment in the trailer that interface with hardware located in the antenna aerial cabin. In addition to providing independent, stand-alone operation, the FEC will also interface directly to the PCTA communications controller for integrated operation with PCTA functions.

The FEC assembly consists of a commercial multibus-type computer providing a card cage, a power supply, and an enclosure with slides. The FEC chassis will contain four commercial computer boards: an Intel 86/14 CPU with a floating-point arithmetic card, a D/A converter, and an IEEE-488 communications card; a RAM memory card; a ROM memory card; and an RS-232 serial communications card. A power meter for the noise-adding radiometer will also be located within the FEC chassis and will consist of an A/D converter module and an additional custom multibus board, the NAR digital board. Software for controlling the FEC will be designed from existing PCTA software modules, with additions and changes made where necessary for implementing specific tasks. Spares for the FEC/NAR will be made at the assembly level.

Control of the Parkes front end will follow the same philosophy that governs the PCTA: operation during telemetry tracking will involve automated monitoring and control through the PCTA array controller, located at the Parkes site; remote monitoring and control by the CDSCC array controller will be possible through the intersite data link. Pre- and post-pass maintenance (independent of the PCTA) will be provided locally through a CRT terminal located in the monitor receiver control cabinet. A second CRT will be located on the third floor of the antenna pedestal dedicated for use during antenna pointing calibration. All three terminals will be able to control equipment and alter the front-end configuration. Selection of the controlling terminal will be made through a switch mounted on the front of the FEC chassis.

The FEC will provide interfaces with the following front-end monitor and control instrumentation (Figs. 6 and 7):

(1) IEEE-488 cabling from the Front-End Controller CPU to an HP quartz thermometer, the 420-MHz test signal synthesizer, the monitor receiver spectrum analyzer, an HP power meter, and (through an IEEE-488 extender to the aerial cabin) the noise diode relay switch controller, the test oscillator upconverter, an AC power controller for the waveguide switches, the monitor receiver, and each of the two downconverters.

(2) Parallel TTL control lines from the front-end controller CPU to the dual TWM control panel.

(3) RS-232 serial communication lines from the FEC serial ports to the following terminals:

   (a) The PCTA communications controller.

   (b) A local CRT terminal for monitor receiver system maintenance.

   (c) A remote CRT terminal for NAR operation during antenna pointing calibration.

   (d) The CCR data acquisition unit.

(4) A 50-ohm coax from the PCTA receiver to the NAR A/D module in the FEC and from the FEC to the noise diode power assemblies in the aerial cabin.

Tasks performed by the front-end controller will consist of:

(1) Providing monitoring and control of the antenna waveguide switches and polarizer driver assembly. This task includes monitoring of telltales showing the true mechanical position of the devices (not provided in 1986).

(2) Measuring system temperature using the Y-factor technique through automation of the waveguide switches, quartz thermometer, dual TWM control panel, and HP power meter. This task includes automatic calibration (zeroing) of the HP power meter.

(3) Performing NAR functions under remote control through automation of the noise diode assemblies and the NAR power meter. This task includes the return of a time-varying analog signal, corresponding to measured system temperature, to the pedestal. It also includes periodic calibration of the noise diodes.

(4) Providing status updates and charting the performance history of the refrigerators and compressors as requested. This task includes the generation of alarm messages on CCR out-of-limit conditions.

(5) Monitoring of alarms from the downconverters, monitor receiver, and test signal upconverter. These alarms include all power supplies, local oscillator power levels, timing, and phase-lock conditions.

B. Detailed Functional Descriptions

1. Waveguide switching and polarizer control. Monitoring and control of the two waveguide switches and polarizer will take place over the IEEE-488 using a remote HP 3488A switch control unit with plug-in HP 44471A relay modules for power control and an HP 44474A digital I/O module for telltale monitoring. A new waveguide switch interface will be built to interface the switch controller to the existing cable harnesses and assemblies. Manual control in the event of hardware failure will be possible from within the aerial cabin.

2. **Y-factor system temperature measurement.** Pre-pass system temperature measurement using the Y-factor technique will be fully automated by the front-end controller. Coordinated operation will consist of:

(1) Instructing the TWM controller assembly to remove all test signal sources from the receiver signal path.

(2) Instructing the monitor receiver to select the appropriate signal path and positioning the waveguide switches to select the desired configuration (sky or ambient load).

(3) Calibrating the HP power meter by switching its input to an internal calibration signal.

(4) Switching the meter to the monitor receiver and measuring the noise power levels.

(5) Measuring the ambient load temperature using the quartz thermometer.

(6) Calculating the system temperature and reporting the results to the operator.

3. **Noise-adding radiometer.** Noise-adding radiometers [2] operate by periodically injecting small, known quantities of noise into the antenna front end and then measuring the resulting increase in system noise power at the receiver. For the Parkes reimplementation, this additive noise will be generated using a DSN noise diode assembly; the NAR power meter in the front-end controller will perform the noise power measurements. During antenna pointing calibration operations, system temperature calculations will be carried out continually, with the FEC supplying a corresponding analog voltage to the pedestal via a D/A converter.

Two noise diode assemblies will be supplied for the Parkes antenna, one for each of the two 8.4-GHz receive chains. Each assembly consists of a noise diode oven and an associated power supply. Each oven contains three diodes, providing noise temperatures of 0.25, 0.5, 1, 2, 4, 8, and 50 K, defined at the maser inputs. The ovens are controlled through their power supply assemblies, each of which contains three independent power supplies, one for each diode. Three relays per supply are used to select the amount of diode current (allowing three noise levels per diode), while a fourth TTL signal modulates the diode on and off. (The diodes are not switched with the power supply relays.)

Each power supply assembly is monitored and controlled through 21 digital I/O lines consisting of relay closures, telltale sensors, and diode modulation input. Both assemblies will be operated through a remote HP 3488A switch control unit containing three HP 44474A digital I/O modules (16 channels per card); coaxial cable run directly from the FEC will supply the modulation control signals. Since one HP controller will already be in place for operating the waveguide switches, common spares will exist for both the switch controllers and the digital I/O modules.

At the other end of the receive chain, noise power measurements will be taken from the inputs of the Parkes telemetry receiver. Each of the two 285- to 360-MHz RF signals will be split 3 dB in the signal select drawer and then fed directly to the power meter in the FEC. The NAR power meter consists of a module comprising an analog-to-digital converter for sampling the noise inputs and a single Intel multibus stitch-wire board under FEC control for accumulating individual power measurements; an averaged output is read over the bus by the 86/14 CPU. Diode control, noise measurement, system temperature computation, and analog output programming are all handled by the CPU, with results included in FEC status displays.

4. **CCR/compressor monitoring.** The CCR/compressor monitor consists of three μMAC 5000 data acquisition assemblies and an IBM PC-XT data acquisition unit (DAU) [3] used for interfacing and data processing. The DAU is located in one of the two front-end control cabinets (Fig. 3) located in the Parkes trailer. One μMAC will be located in the aerial cabin to monitor both CCRs (Fig. 4), while the other two μMACs will be in the compressor room (Fig. 8) to monitor one compressor each; data will be sent from the μMACs to the DAU at 1-minute intervals. Communication between the μMACs and the DAU will be serial RS-232 and will use a coaxial cable daisy-chained to all devices. An additional RS-232 port on the DAU will provide the interface to the FEC via an IBM PC serial communications card.

The data acquisition unit will be located in one of the two Parkes front-end control cabinets and will be dedicated solely to CCR system monitor tasks. The DAU will continuously display CCR and compressor parameters, updating the screen once a minute as data is received from the antenna. These parameters will also be echoed to the FEC, and the most up-to-date values will be used to generate routine PCTA status displays.

Monitored CCR/compressor parameters include:

(1) CCR stage temperatures (4.5 K, 15 K, and 70 K).

(2) Reserve CCR heat capacity (percentage of normal).

(3) Helium pressures (supply, refrigeration return, JT return, tank, and oil stack differential).

(4) Joule–Thomson stage helium flow.

(5) Motor phase currents (A, B, and C).

(6) Motor temperature.

(7) Compressor temperatures (first and second stage).

(8) Vacuum pressure in the CCR vessel.

In addition to the CCR/compressor parameter values, each record sent by the DAU to the FEC will be formatted with status flags indicating whether each value is within acceptable limits. (All CCR/compressor alarm limits are to be entered at the DAU keyboard.) Any out-of-limits conditions will cause the FEC to immediately send a PCTA-type alarm message (including an audible tone) to each FEC terminal.

In order to keep track of performance history, the DAU will time-tag and log the CCR/compressor data to its hard disk every 15 minutes. Given the capacity of the disk, an entire year's worth of data (96 records/day) can be recorded. In addition to the long-term storage in the DAU, the front-end controller will keep track of the most recent 72 hours' worth of data transmitted to it (in 1-minute intervals). This performance history will be made available in two forms: upon specifying a start date/time and a stop date/time, one or more parameters can be either displayed as a low-resolution graph (80 X 24 characters) or tabulated in columns. Short-term history (up to 72 hours old) will have a maximum resolution of 1 minute; long-term history will have a 15-minute resolution. Data records that are not found in the FEC short-term cache can be automatically requested from the DAU hard disk log, indexed by day of year, time of day, and CCR/compressor system number.

5. Alarm monitoring. The downconverters, monitor receiver, and test signal upconverter all have built-in alarms to indicate failures or performance degradation. These alarms are detected by polling the equipment over the IEEE-488 and will be monitored by the front-end controller. Alarm conditions will generate a PCTA-compatible alarm message and the condition of all monitored parameters will be included in routine FEC status displays.

Alarms monitored include:

(1) Downconverters:

- (a) DC power: Detects if any power supply voltage drops by more than 15 percent.
- (b) Phase lock: Detects if the 8.1-GHz local oscillator PLL is phase-locked.
- (c) Five-megahertz standard: Detects low or missing 5-MHz references from the station FTS.
- (d) Low power: Detects low local oscillator power.
- (e) Sum: Detects if any of the above alarms are true.

(2) Upconverter:

- (a) DC power: Detects if any power supply voltage drops by more than 15 percent.
- (b) Phase lock: Detects if the 8.1-GHz local oscillator PLL is phase-locked.
- (c) Five-megahertz standard: Detects low or missing 5-MHz references from the station FTS.
- (d) Low power: Detects low local oscillator power.
- (e) Sum: Detects if any of the above alarms are true.

(3) Monitor receiver:

- (a) DC power: Detects if any power supply voltage drops by more than 15 percent.
- (b) Sum: Detects if any of the above alarms are true.

V. Dual TWM Refurbishment and Performance

The two TWM/CCRs were tested at JPL in the condition received from ESA. One of the TWM/CCRs had a vacuum leak resulting from a damaged waveguide window, and both TWMs had shorted wires in their internal cable harnesses. As a result, both TWMs were removed from the RF package and repaired prior to testing. Test results of the TWM gain/bandwidth curves (Fig. 9) indicated that both TWMs required adjustment of the gain/bandwidth shape in order to achieve the specified 100-MHz, 3-dB bandwidth. The gain/bandwidth curves of the TWMs were adjusted to meet the Block IIA TWM specifications [1] by altering the magnetic field with a change in the length and/or thickness of the steel shims mounted on the top and bottom of the structure [4]. The final gain/bandwidth curves achieved with both TWM 1 and TWM 2 are shown in Fig. 10.

The measured equivalent input noise temperature (referred to the room temperature input flange) is shown in Fig. 11 for both TWMs. The noise temperatures were determined by attaching a high-quality feedhorn to the waveguide input flange and then measuring the Y-factor obtained when alternately viewing the "cold" sky and an ambient termination microwave adsorber.

Refurbishment of the TWM/CCRs consisted of the following:

(1) Repairing CCR vacuum leaks.

(2) Installing new internal wire harnesses and temperature sensor mounting brackets in both CCRs.

(3) Adding an additional temperature sensor to the 15-K to 4.5-K heat exchanger on both CCRs to enable the CCR data acquisition system to monitor the percentage of CCR reserve cooling capacity.

(4) Repairing and upgrading the solid-state pump source assembly. Gunn oscillators and other waveguide components damaged by corrosion were replaced with new components, and new modulator/protect assemblies were installed to upgrade to the latest Block IIA requirements [5].

VI. Conclusion

A PCTA D/E-level design review for the Parkes front-end system was presented in November of 1987. The response indicated that the system with the new front-end controller, noise-adding radiometer, CCR data acquisition unit, system alarm monitoring, and refurbished RF front end will meet all station operation and maintenance requirements as well as the Voyager Neptune encounter project requirements.

Acknowledgments

The Parkes front-end system refurbishment and reimplementation is the product of the Parkes front-end team members, including the authors, R. Cardenas, L. Fowler, J. Kovatch, R. Quinn, T. Sweeney, R. Zanteson, and all members of the Microwave Electronics Group under the supervision of S. Petty. Thanks are also due to L. Hileman for his software contribution to this task.

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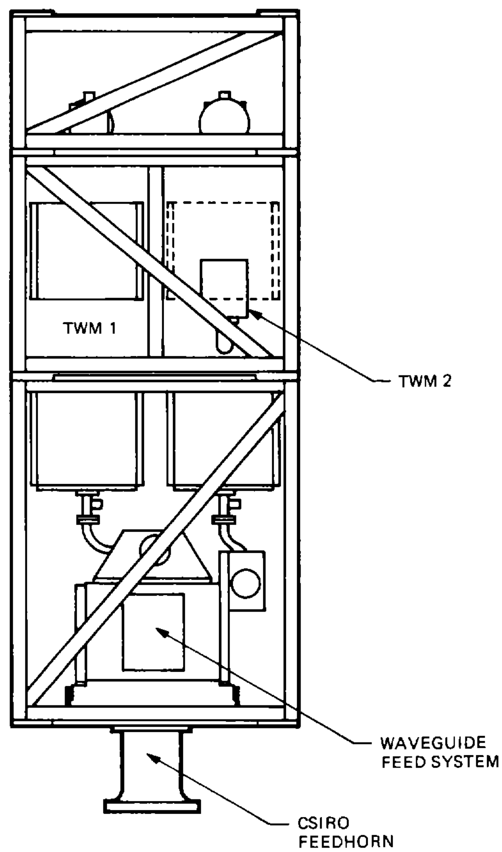

Fig. 1. Parkes RF package

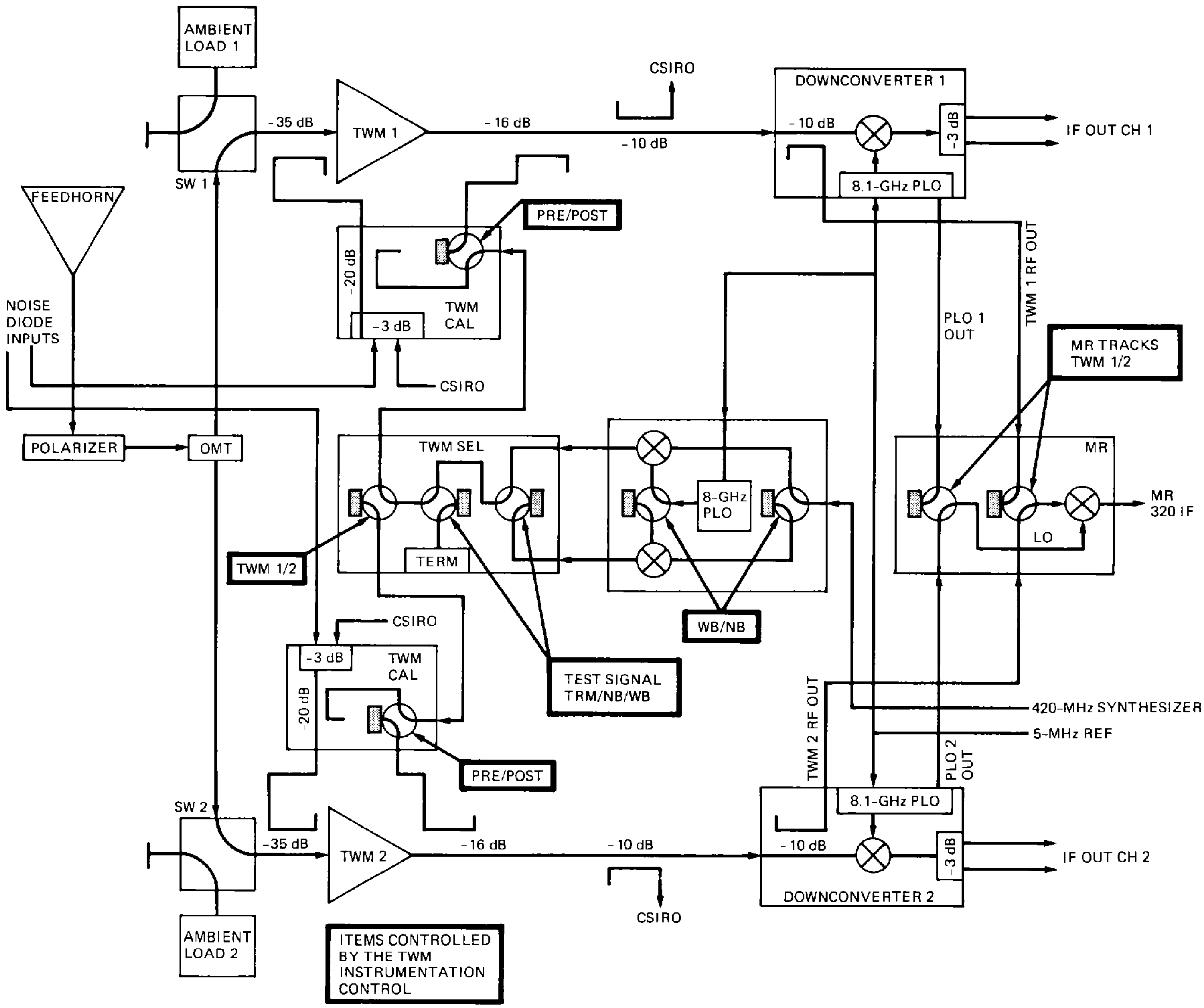

Fig. 2. Parkes RF configuration

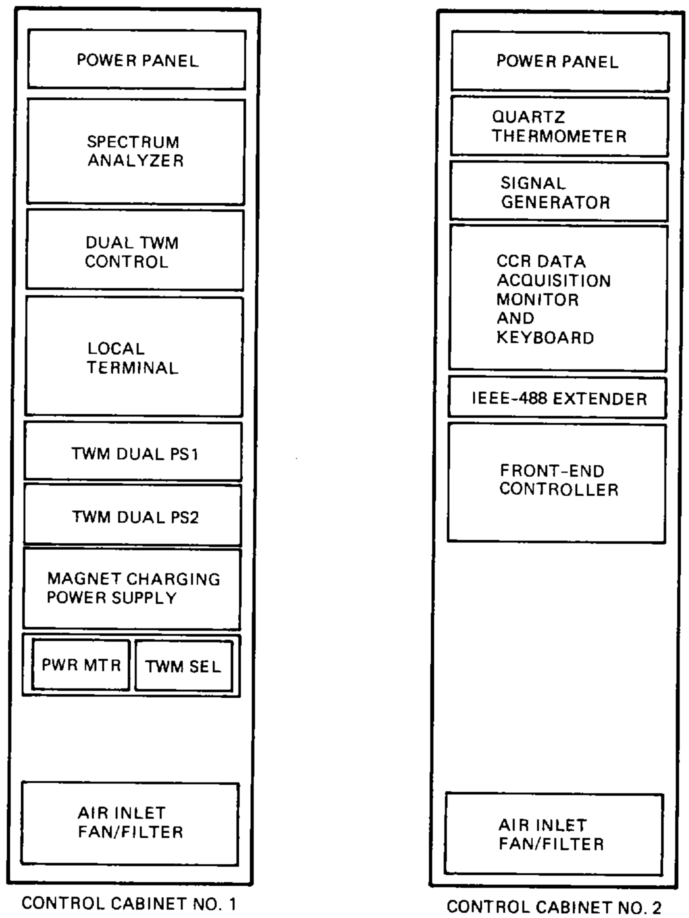

Fig. 3. RF front-end control cabinets

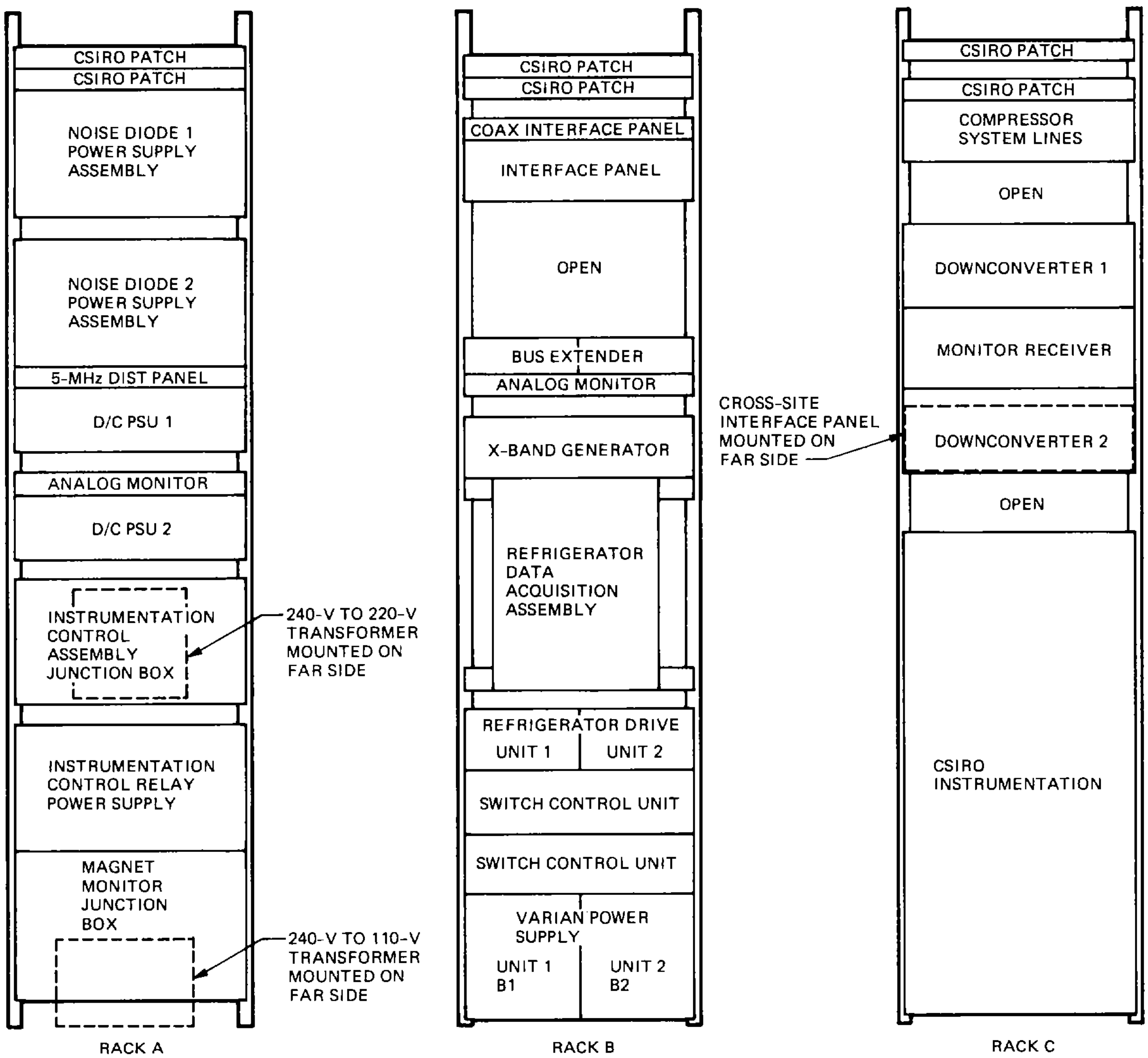

Fig. 4. Aerial cabin racks for reimplementation at Parkes (rack A used by ESA)

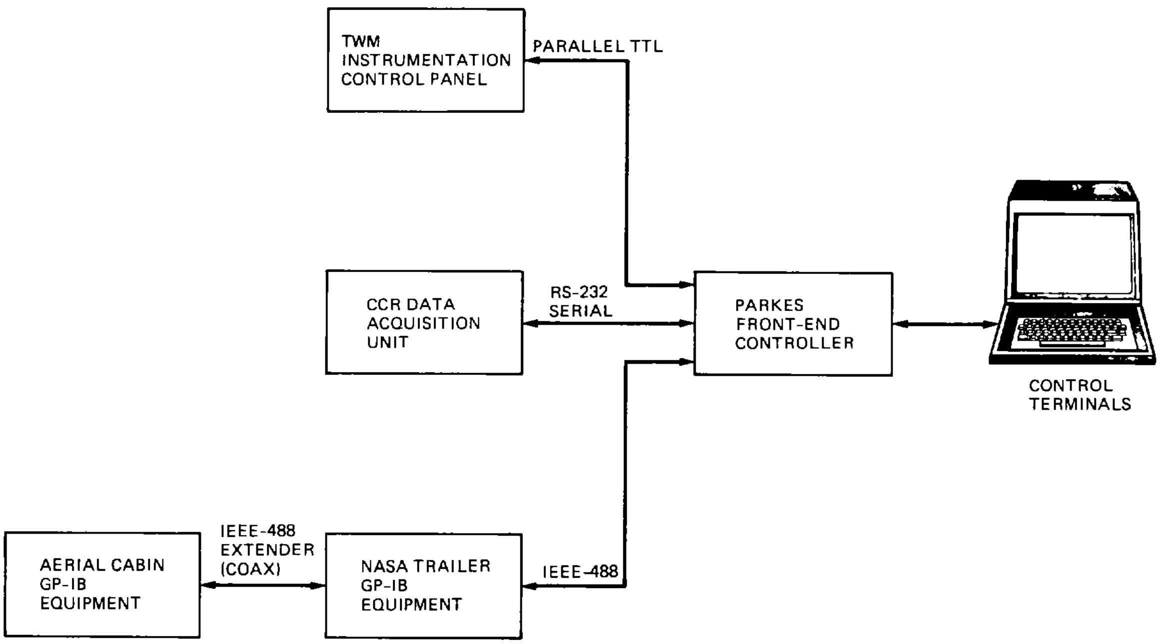

Fig. 5. Front-end monitoring and control block diagram

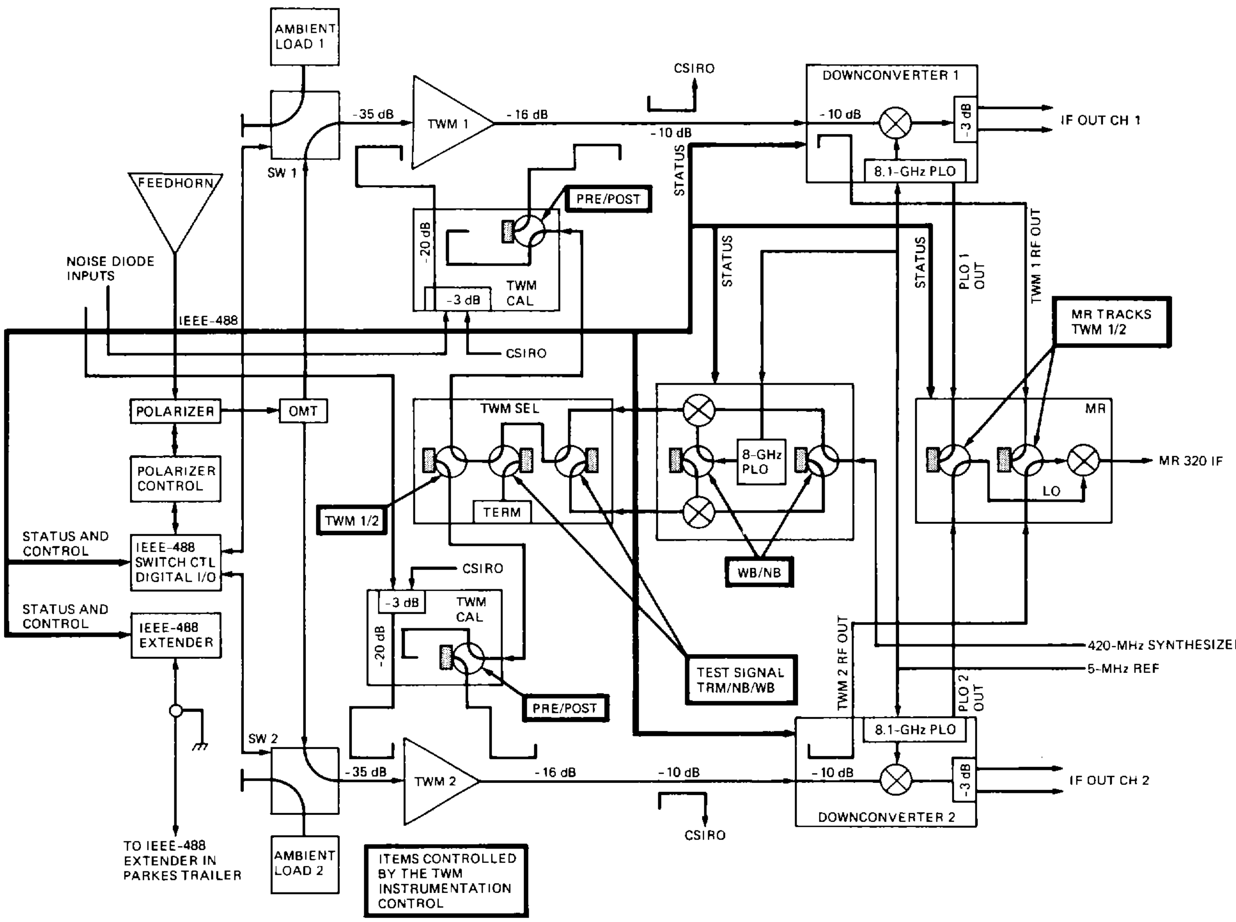

Fig. 6. Control flow diagram: antenna racks

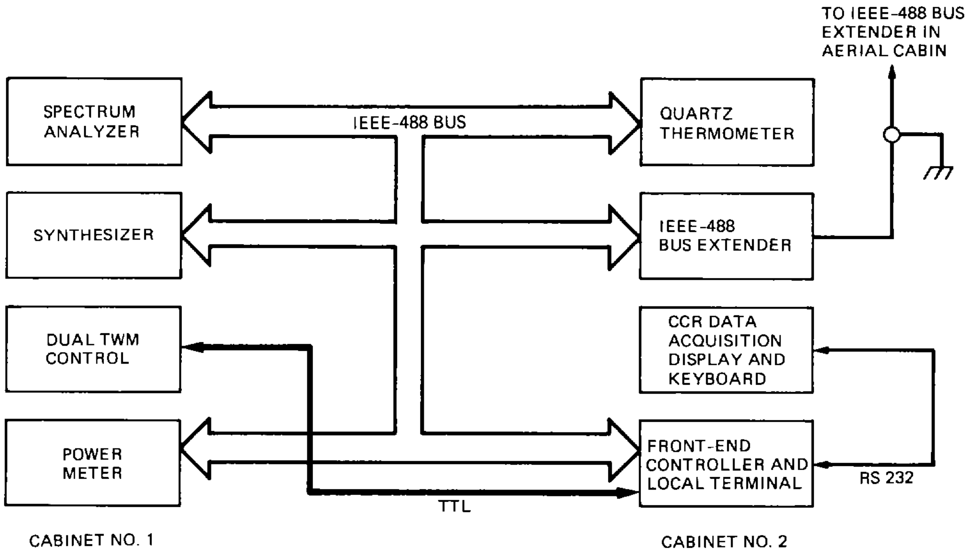

Fig. 7. Control flow diagram: control cabinets

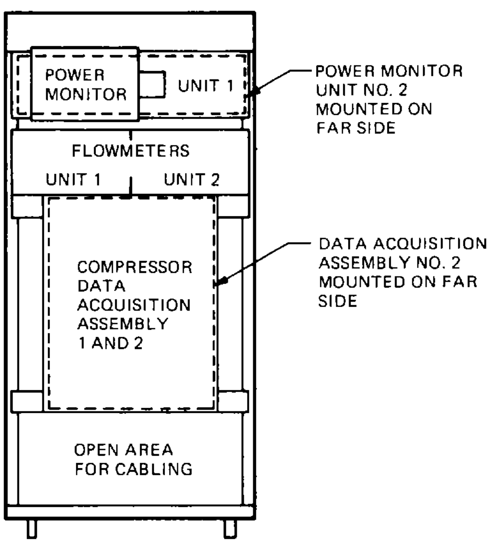

Fig. 8. Compressor instrumentation half rack

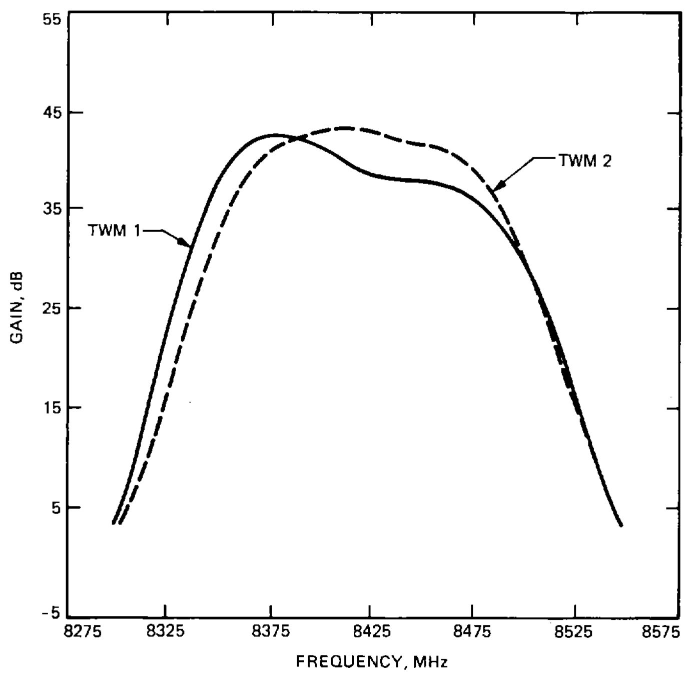

Fig. 9. TWMs 1 and 2 gain/bandwidth curves prior to adjustment

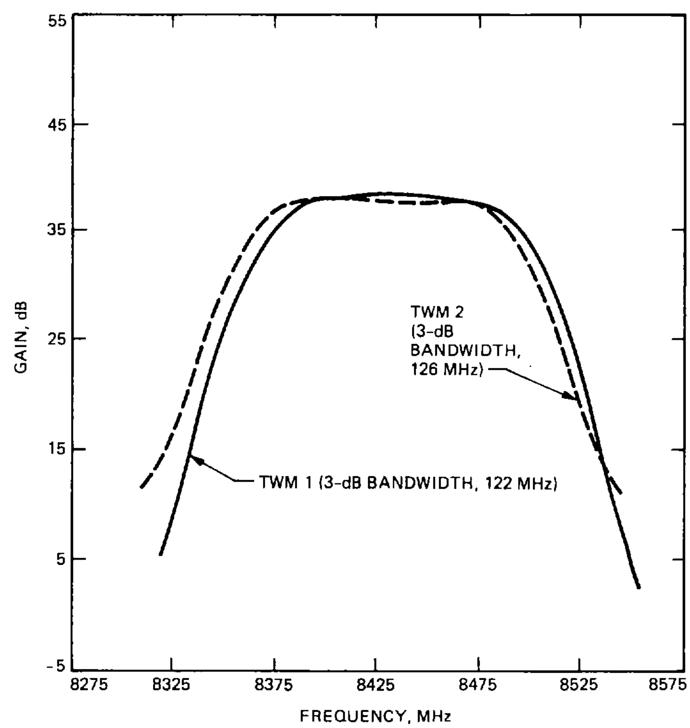

Fig. 10. TWMs 1 and 2 gain/bandwidth curves after final adjustment

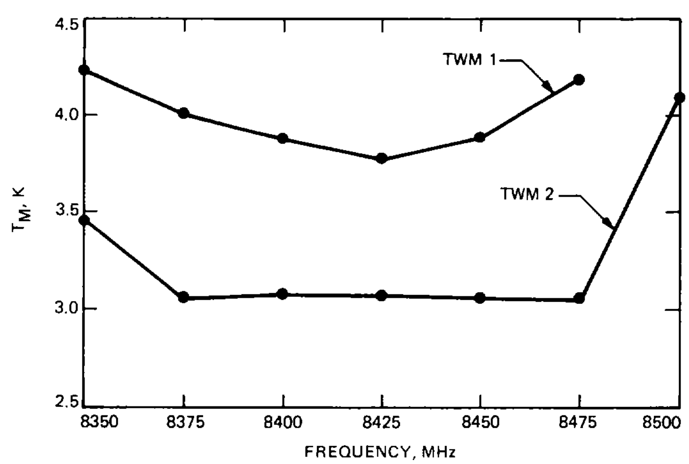

Fig. 11. TWMs 1 and 2 equivalent input noise temperature